ENSAR-ARES EU-FP7 collaboration

Atomki ECR group work summary

2013 June – 2014 November

Task 1: Plasma heating, wave-plasma interaction

Task 3: Production of metal ion beams

Task 2: Ion beam formation and transport

Task 1: Plasma heating, wave-plasma interaction

BEFOREHAND:

- 2002-2003, Atomki, 14.5 GHz ECRIS, fixed frequency
- Atomki-NIST-UniDEB collaboration
- X-ray plasma photos by a 1.4 megapixel pinhole camera
- Energy range: 1-20 KeV
- Resolution 180 eV

Goals:

- ❑ First X-ray ECRIS photos
- ❑ Simple comparisons

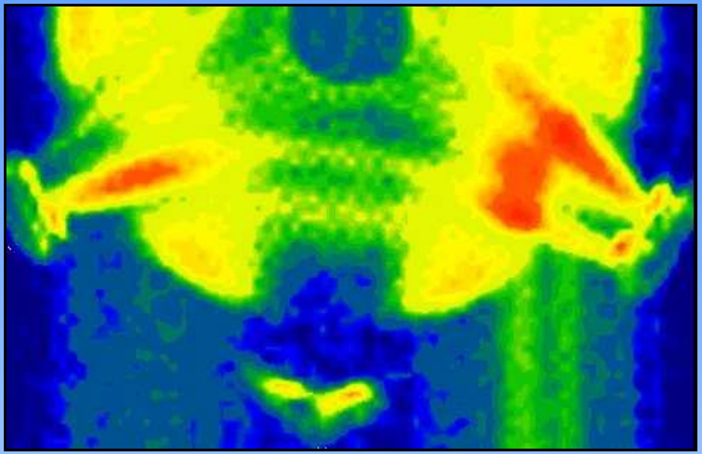
- *S. Biri et al: Imaging of ECR plasmas with a pinhole X-ray camera, RSI 75 (2004) 1420*
- *E. Takács et al., Spatially resolved X-ray spectroscopy of an ECR plasma - indication for evaporative cooling. Nuclear Instruments and Methods B235 (2005)120-125*

Conclusions (ICIS2003, Dubna)

X-ray pinhole camera measurements at the 14.5 GHz ATOMKI-ECRIS

Good spatial resolution and post-proccessing energy filtering

Realistic plasmas (LCI, HCI, extraction, tricks)



- Full-size images (LCI plasmas) show the spatial placement of different X-ray sources (energetic electrons hit the chamber wall, plasma ions)
- Selected regions images (both LCI and HCI plasmas) give information to understand better the effect of some tuning parameters (electrode voltage, gas mixing, microwave power, magnetic field etc.).

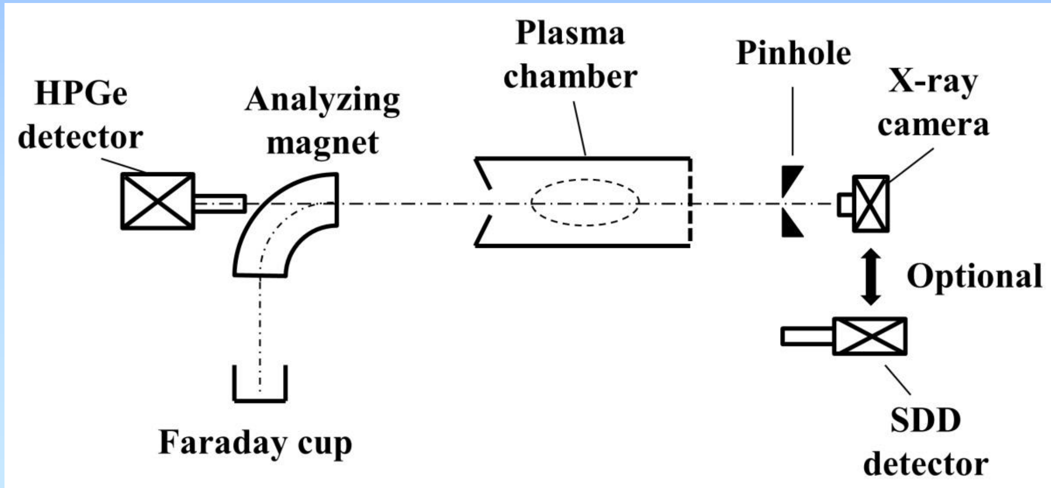
Task 1: Plasma heating, wave-plasma interaction

NOW:

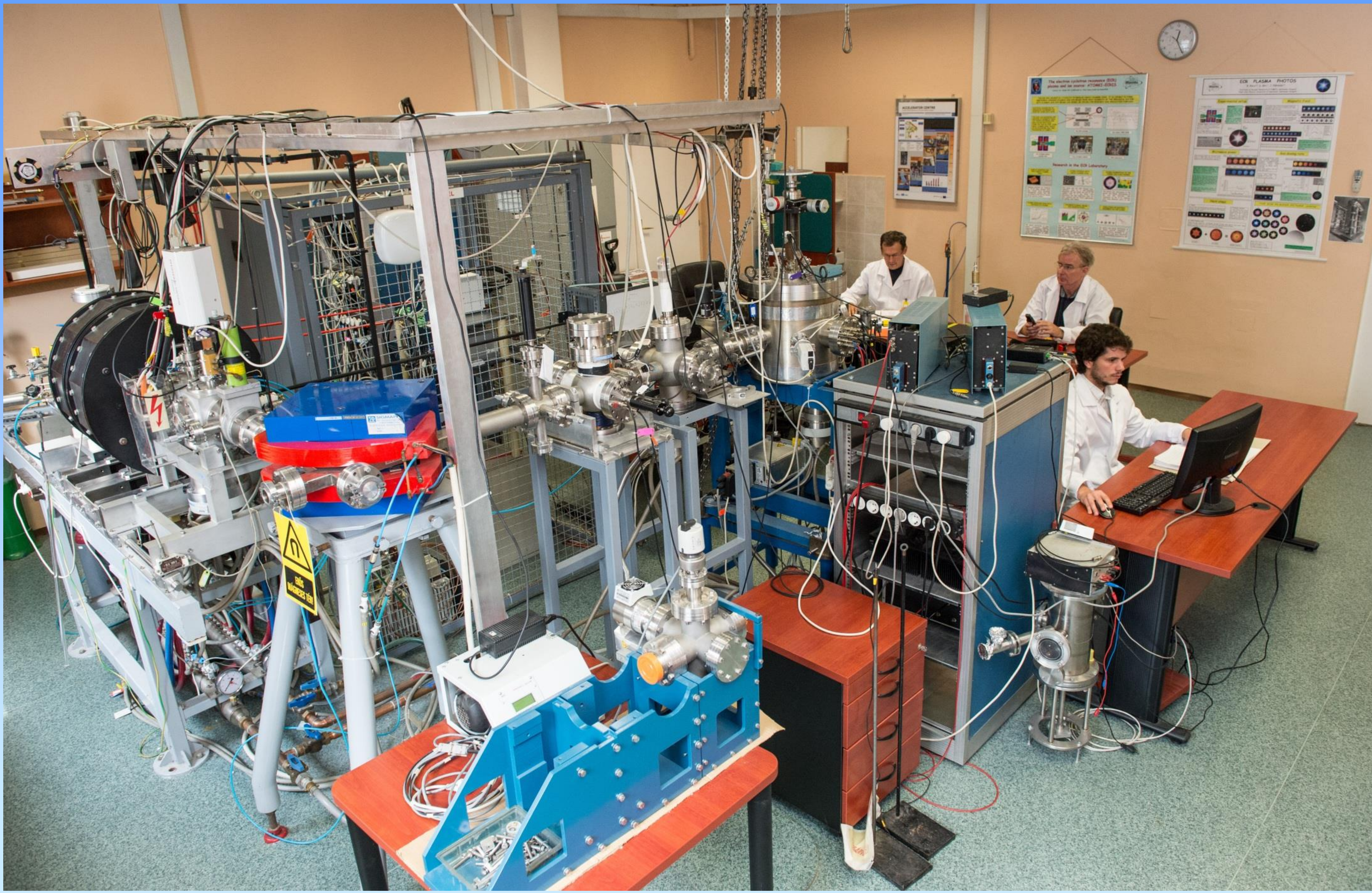
- 2014 , ENSAR-ARES (Atomki-INFN/LNS) collaboration
- Atomki, 8-18 GHz ECRIS
- X-ray diagnostics with SDD and Ge detectors and with pinhole camera
- Energy range: 0.5 – 400 KeV
- Resolution: 125 eV / 2.45 KeV

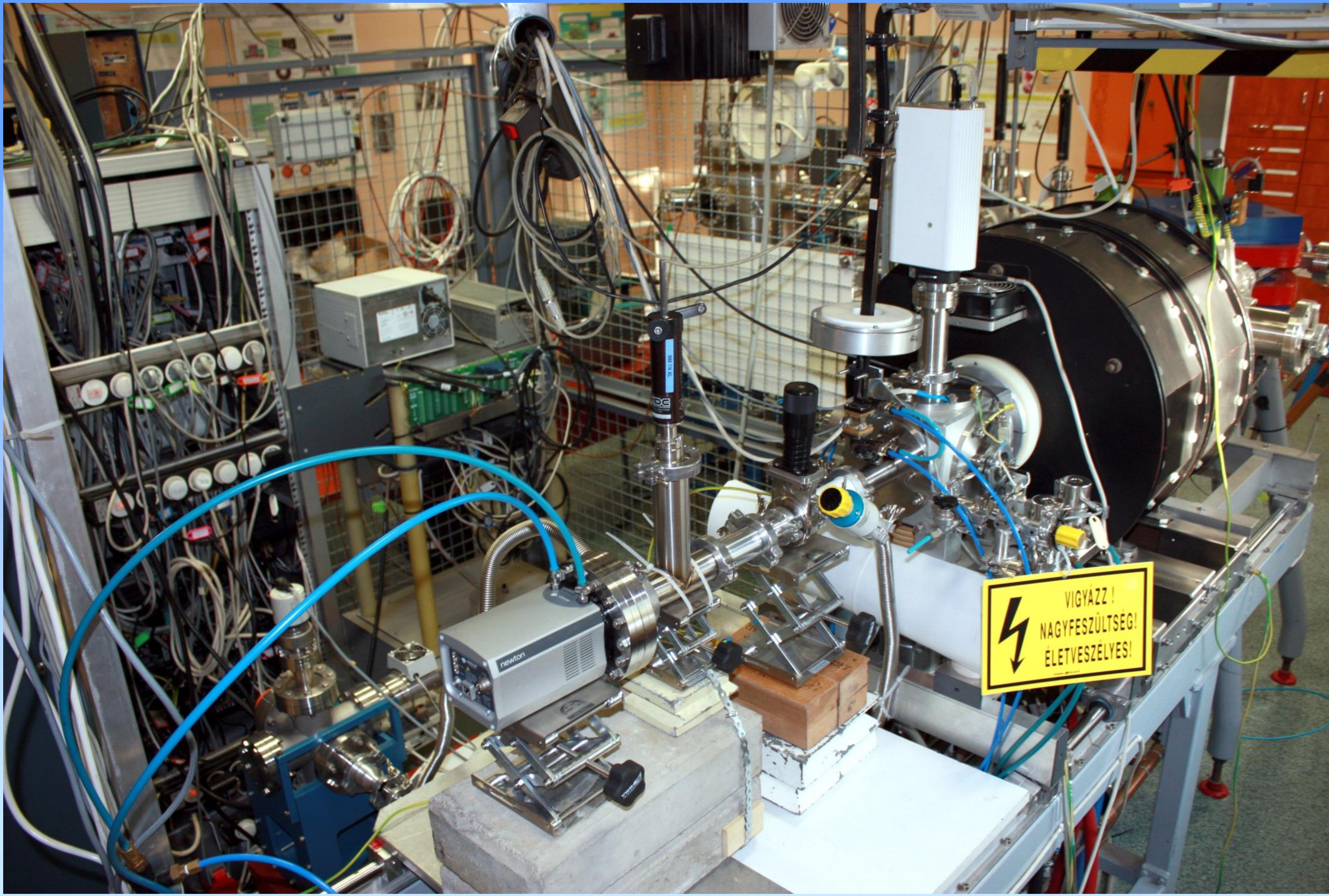
Goals:

- Frequency effects
- Magnetic field effects
- (Gas mixing effects)



First experiment: 3-13 November 2014


ACCELERATOR CENTRE
Research in the ECR Laboratory
ECR PLASMA PHOTOS


VIGYÁZZ !
NAGYFESZÜLTSÉG!
ÉLETVESZÉLYES!
newton

Measurements plan and goals

Freq. [GHz]
12,8
12,84
12,88
12,92
12,96
13
13,04
13,08
13,12
13,16
13,2
13,24
13,28
13,32
13,36
13,4

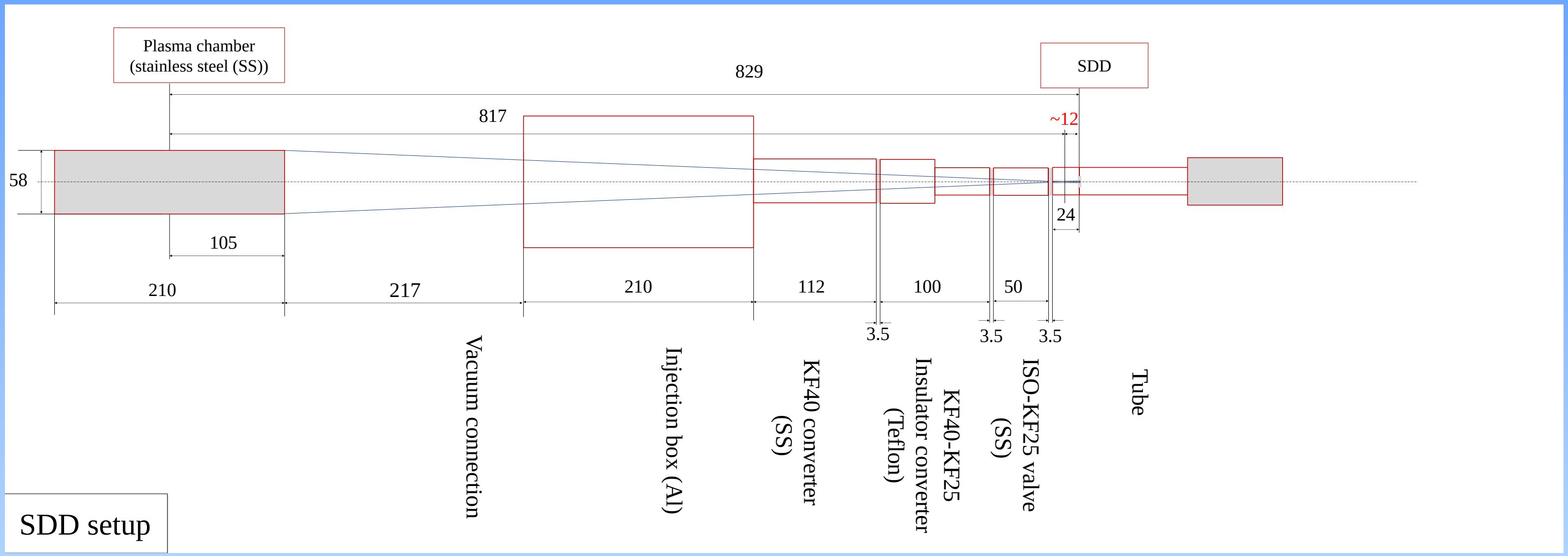
RF power	gas pressure
30 W	3,50E-06 mbar

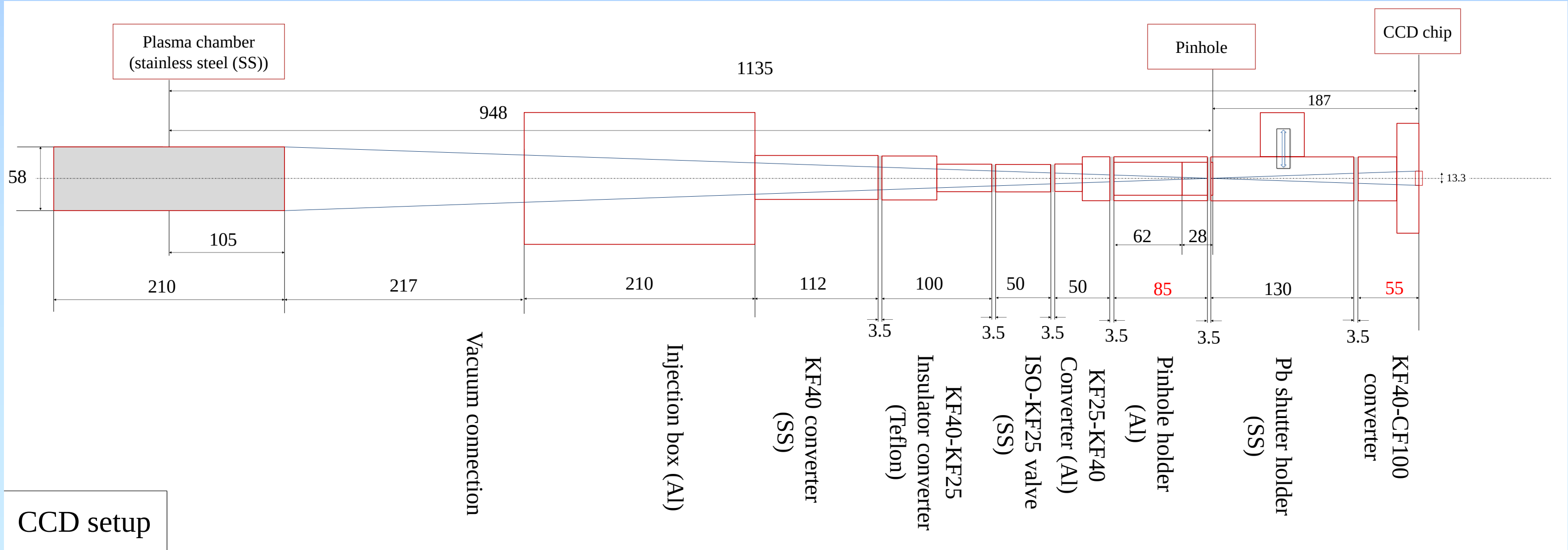
Ext. Voltage	Gas type
10 kV (beam ON)	Argon
	Argon+Oxygen

Coils (inj/mid/ext)
100% each
80% each
60% each

Observation of spectral density and temperature variation in the low/high energy part of the spectrum (warm electrons $1<E<30$ keV; hot electrons $50<E<300$ keV) versus RF frequency, coils setup (high/low mirror ratio), gas mixing.

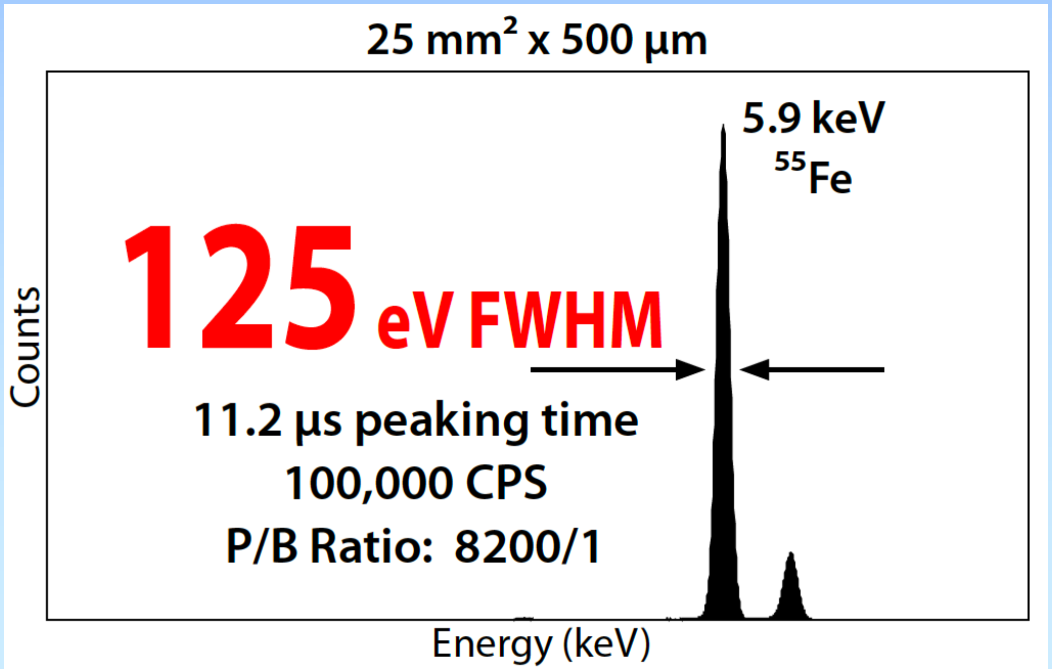
Layout for the SDD and the CCD setup



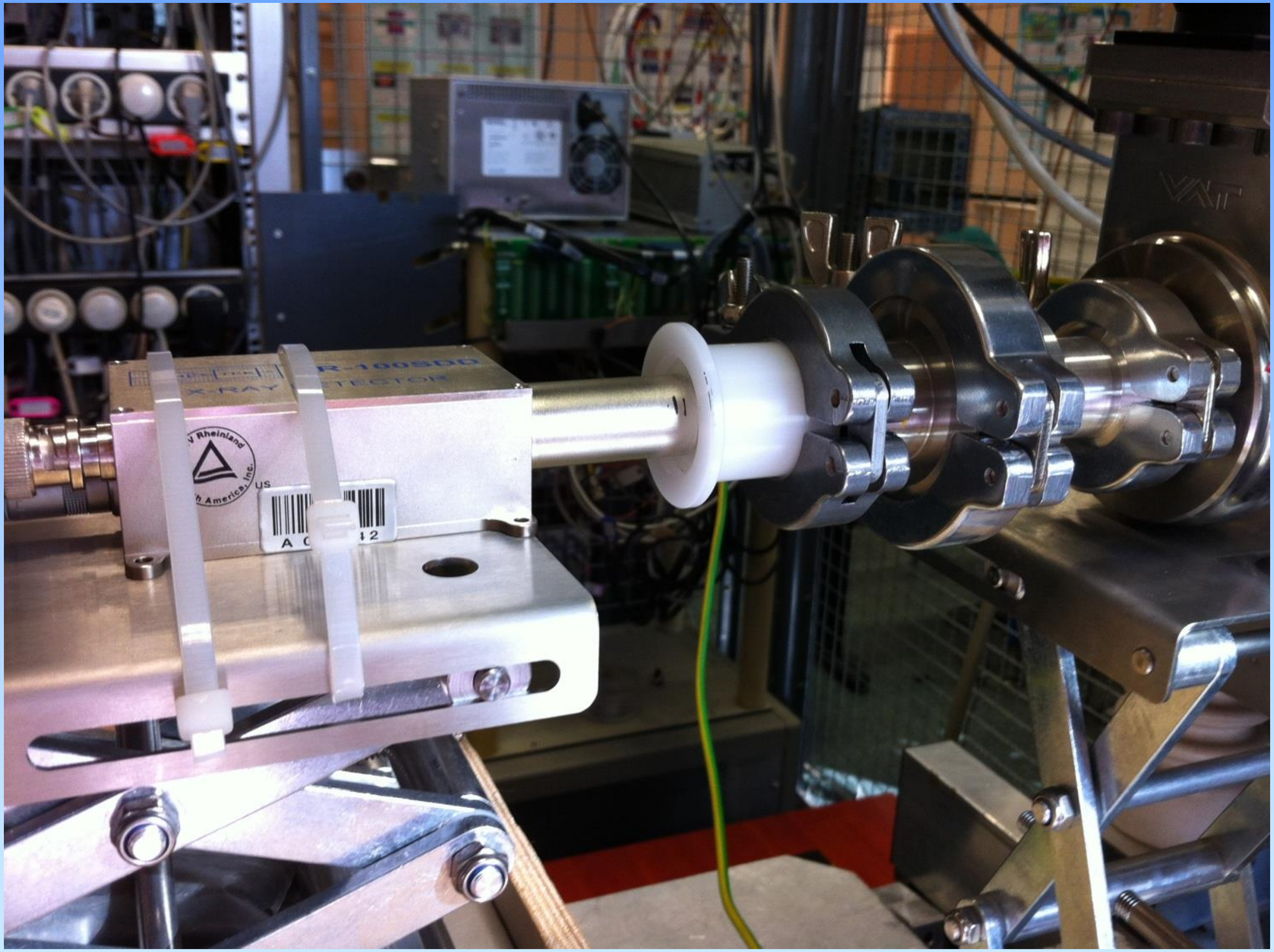


Amptek Silicon Drift Detector

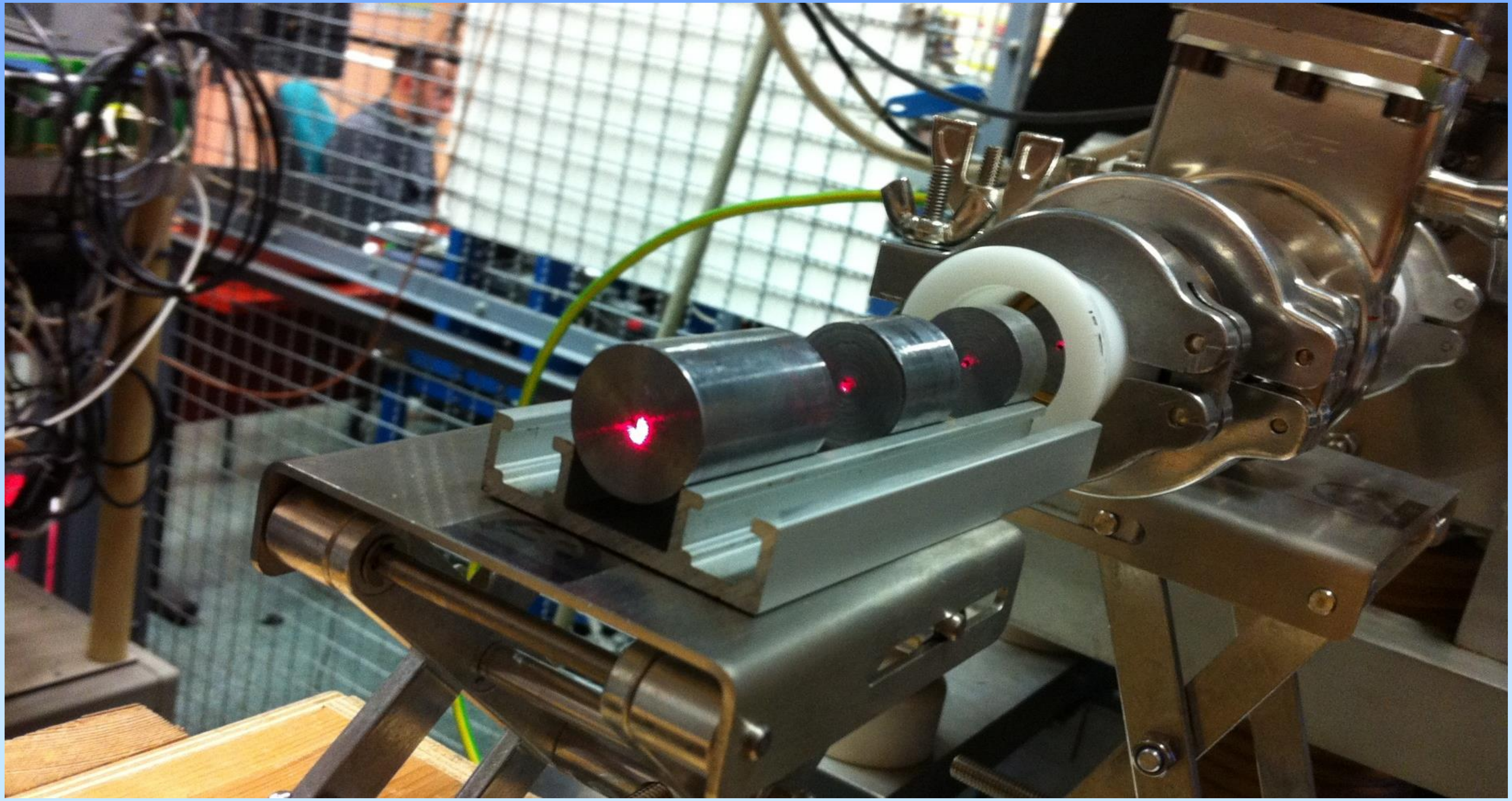
- High energy resolution
- High number of detectable counts per second
- High P/B ratio



SDD: short collimator

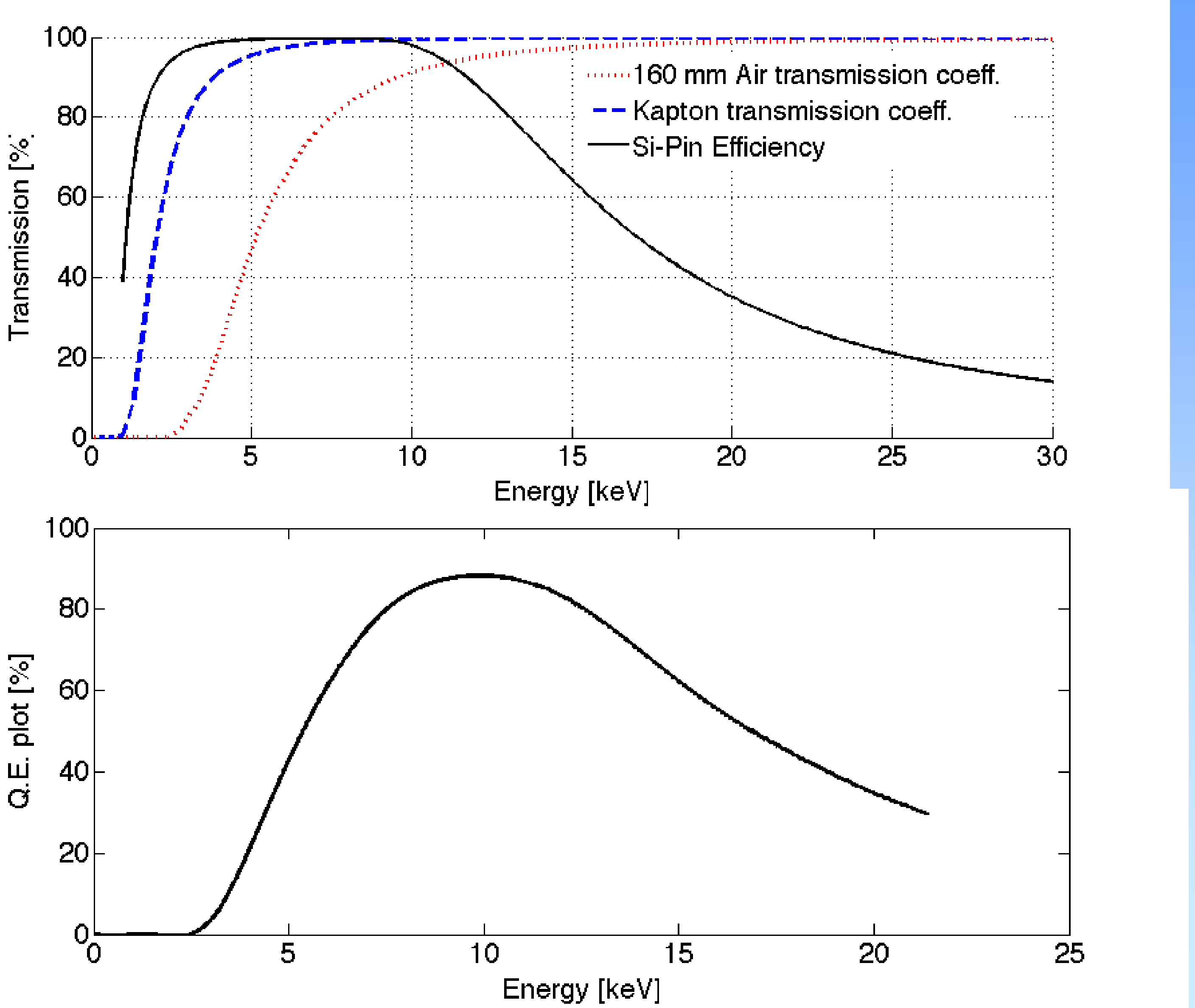


SDD long collimator configuration 1

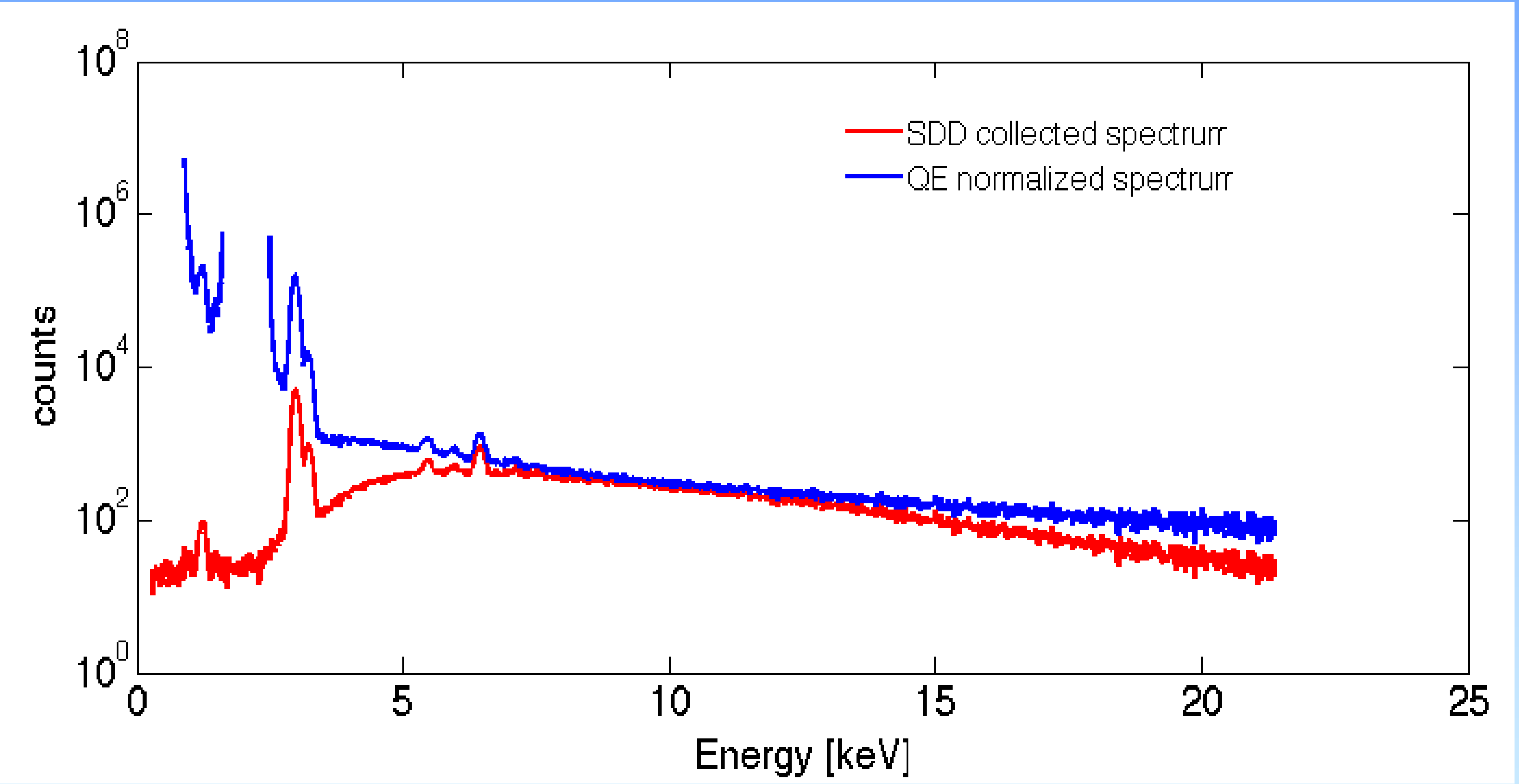


SDD long collimator configuration

Quantum Efficiency plots of the SDD in the "long collimator" setup

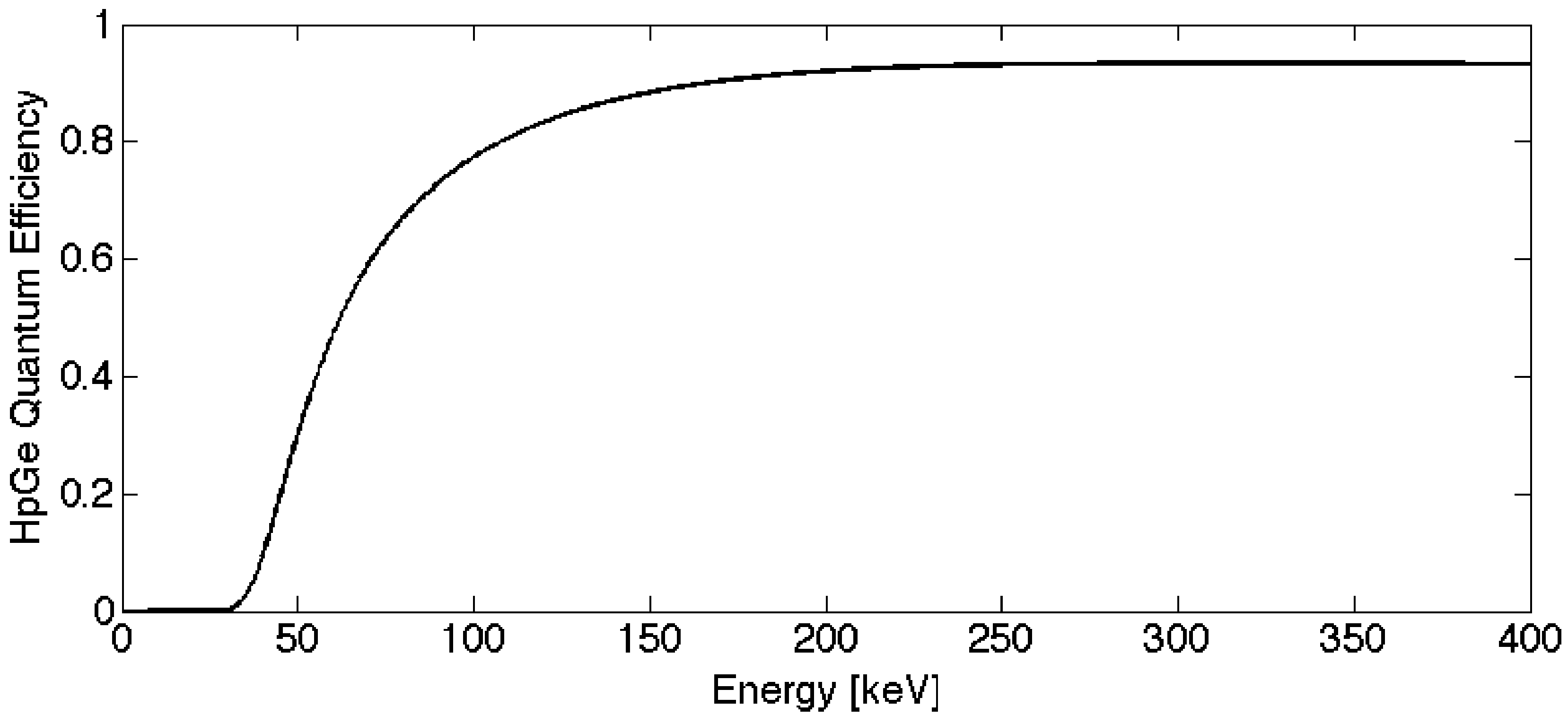


Typical spectrum of SDD during measurements at ATOMKI



HpGe detector setup at ATOMKI

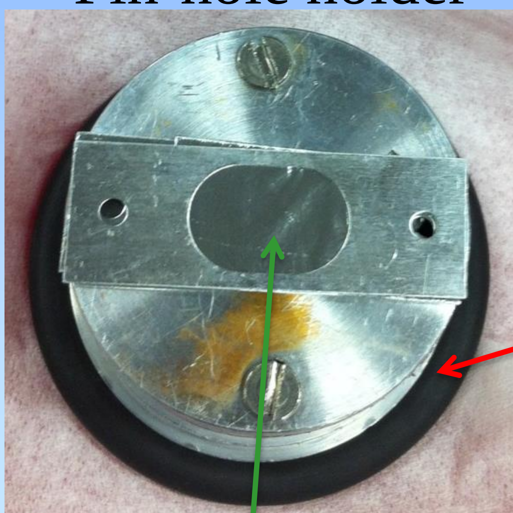
HpGe detector Efficiency

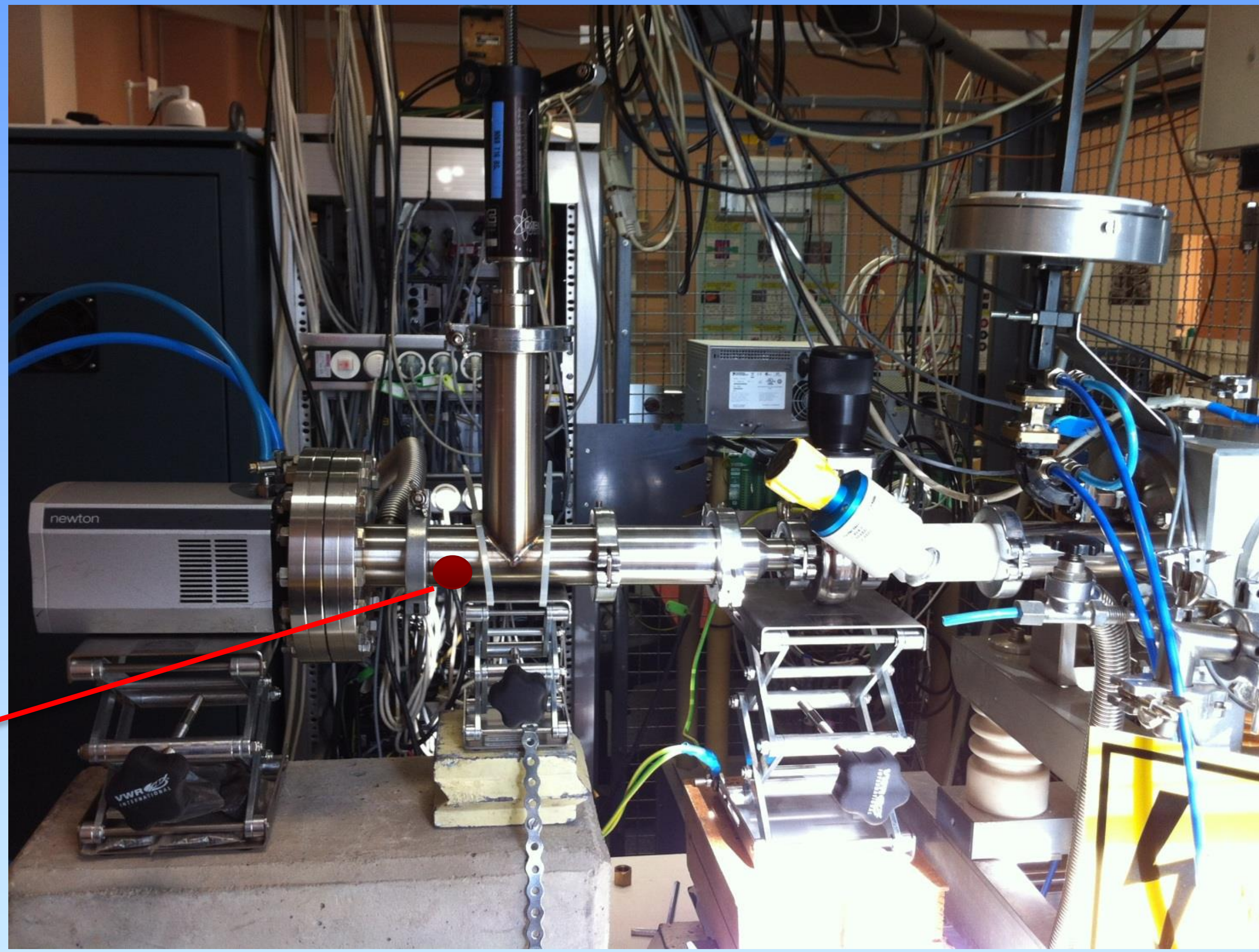


Energy Resolution: 2.42 keV at 1.33 MeV
Detector Diameter: 49.2 mm
Detector length= 81.8 mm
Absorbing layers: Alluminum of 1 mm

CCD setup at ATOMKI

Pin-hole holder



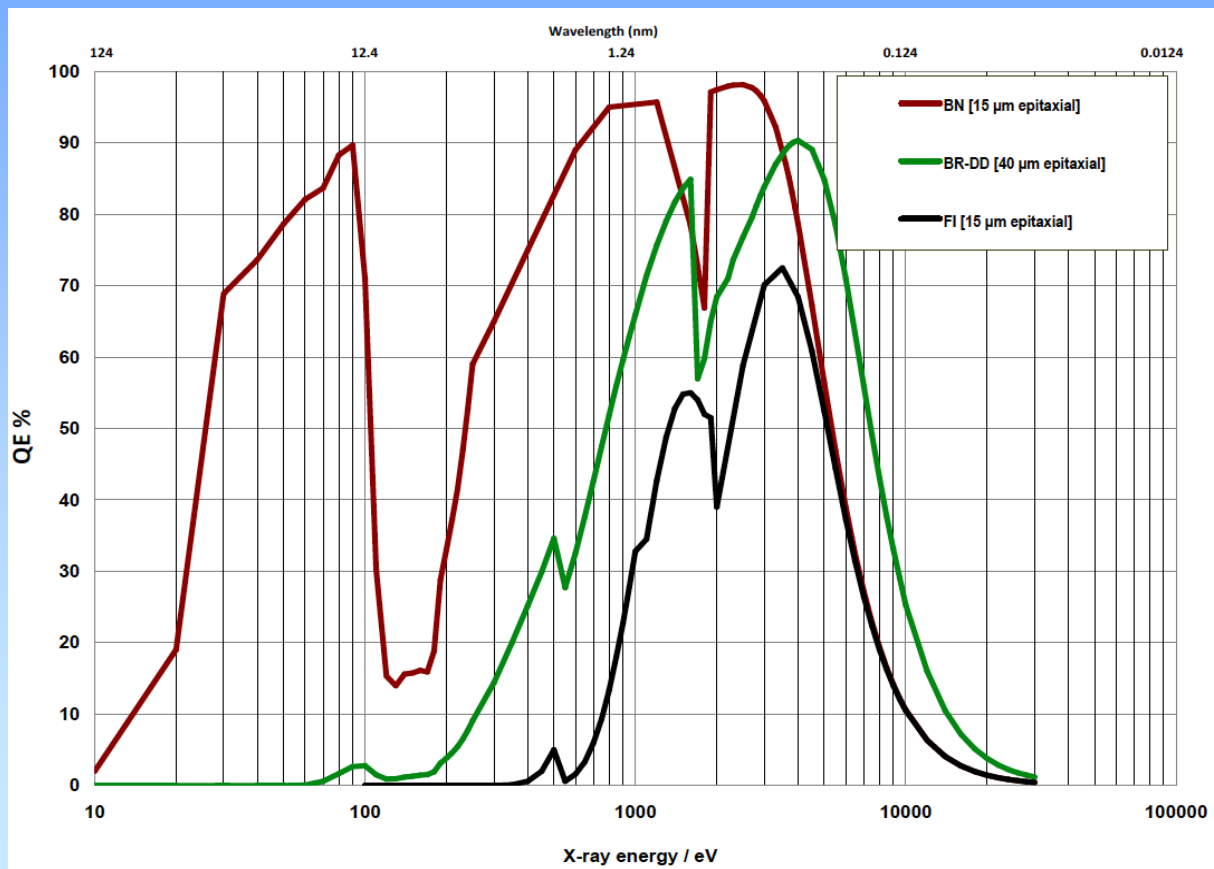


Aluminum Window (6 mcrm)

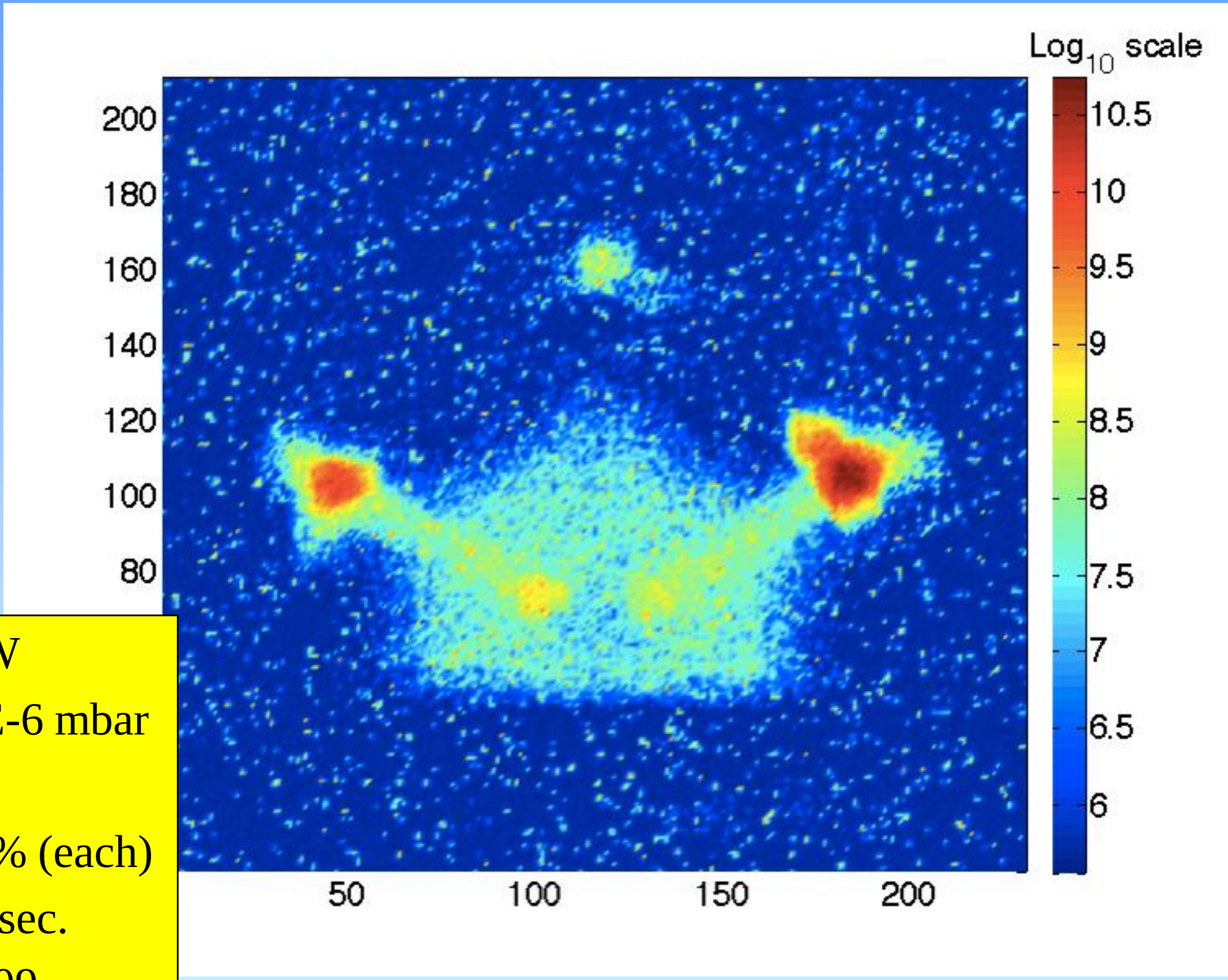
CCD technical datasheet

Active pixels	1024 x 255 (1024 x 256 for BR-DD model) or 2048 x 512
Pixel size (W x H)	26 x 26 μm or 13.5 x 13.5 μm
Image area	Up to 27.6 x 6.9 mm
Register well depth (typical) Standard mode High Capacity mode High Sensitivity mode	 1,000,000 e^- 600,000 e^- 150,000 e^-
Maximum cooling	-100ºC
Maximum spectra per sec •2	1612
Read noise	2.8 e^-
Dark current	As low as 0.00007 e^-/pixel/sec

CCD Quantum efficiency curve



First X-ray camera photos – an example



- P_rf: 30 W
- pressure: 3.6E-6 mbar
- gas: Ar
- Coils: 100% (each)
- Exposure time: 15 sec.
- Magnification: 0.09

Next plans (2015, MIDAS?)

- Analysis of the present measurements (long)
- Gas mixing studies (e.g. Xe+Ar)
- Higher mw-power at narrower frequency (with biased disk)
- Looking through the plasma not on the axes using special plasma electrodes
- Two-frequency mode with X-ray detectors and cameras

Task 3: Production of metal ion beams

2010 – 2014 - (2015)…

The users of the Atomki-ECRIS require non-standard ion beams to irradiate medical implants

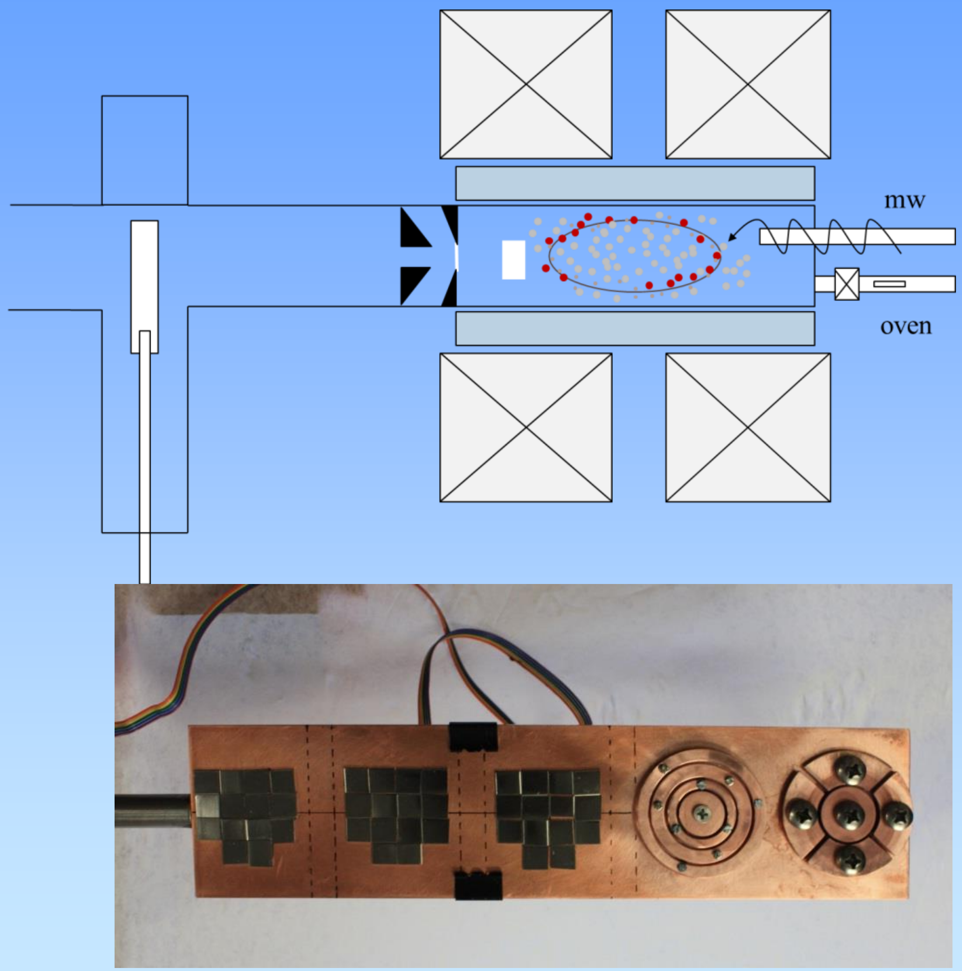
	A	B	C
Target material	Ti	Ti	ZrO_2
Beam	Au	Ca	Si

Key : surface functionalising on the nano-scale!

Requirements:

- Penetration just under the surface (5-30 nm): low extraction voltage and low charge
- High dose rate, 1E17 ions/cm2: difficulties with oven or sputtering
- Large beam size: defocusing necessary, inhomogenity

Sample holder



The movable sample holder positioned after the extraction optics of the ECRIS. The extracted beam hits one of the five parts of the holder, from right to left: 5-segments beam monitor, 4-rings beam monitor, group of samples to be irradiated 1-2-3

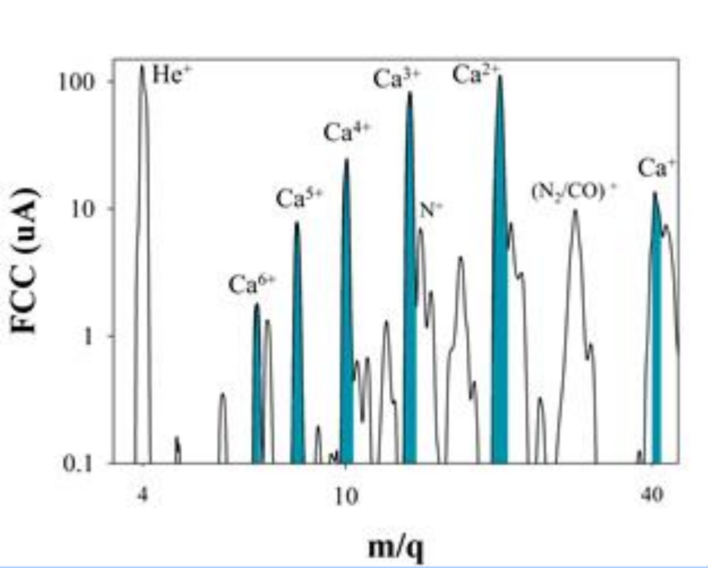
Calcium beam

- Filament oven (Pantechnik) on the axis, inside the plasma chamber
- Pure calcium + helium support gas.
- Weak magnetic trap + low microwave power (50 W)
- Temperature between 500ºC and 700ºC.
- Strong getter effect was observed.

- Ion beam intensities of 100 microamper of the tuned charge state (Ca^{+} or Ca^{2+} or Ca^{3+}) were obtained.

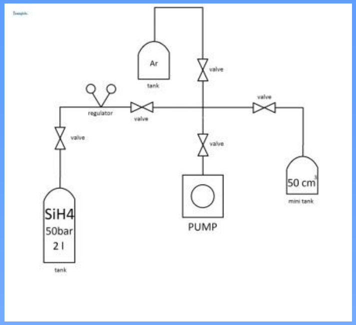
- It allowed us to irradiate large sample surfaces (15-20 cm^2) with the required dose (10^{15} – 10^{17} ions/cm^2) in reasonable time (10 min – 10 hours).

- Drawbacks: low material efficiency and high simultaneous He dose



Typical calcium ion beam spectra. The extraction voltage and the temperature of the oven were 10 kV and 600 C respectively. The purity of the spectra is caused by the strong getter effect. The plasma was optimized for Ca2+.

Silicon beam

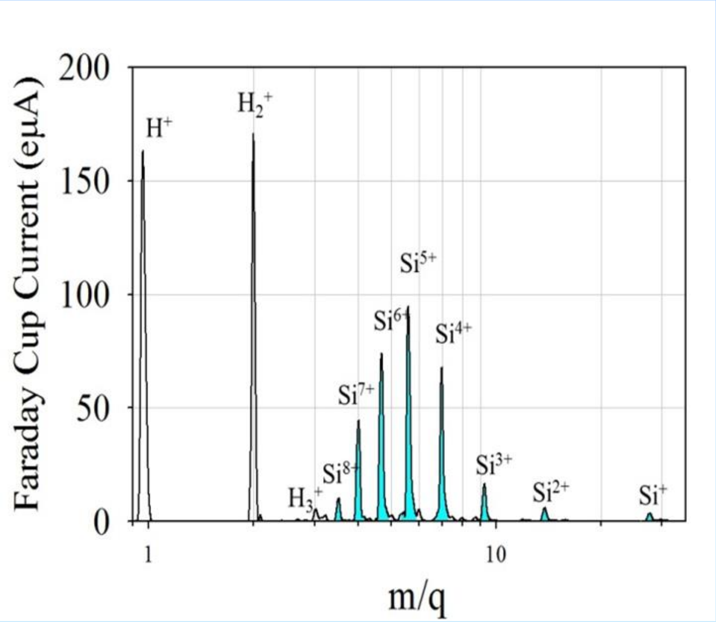


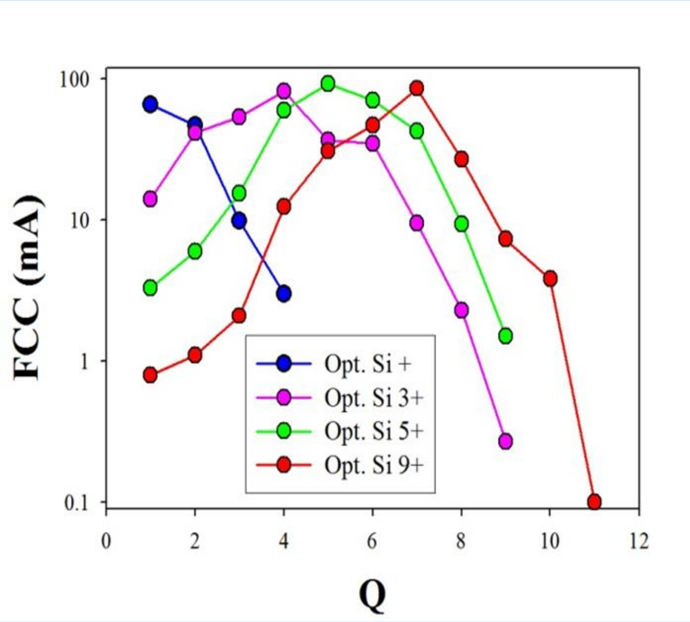
- Silane gas (SiH_4) was selected
- Special care (flammable, auto ignition)
- Transferring the gas from high volume high pressure (2 dm^3 and 50 bar) gas bottle to a smaller (50 cm^3 and 1.5 bar) one.

➢ 100 microamper of any charge state was easily obtained.

➢ Short irradiation time

➢ But high simultaneous H+ and (H2)+ dose hits





Combination of two ECRIS calculations: plasma electrons and extracted ions

Atomki-GSI collaboration within ENSAR-ARES, 2012-14

(Presentation of the ECRIS14 talk of S. Biri in 2 parts)

OUTLINE

1. MOTIVATION
2. THE ECRIS
3. THE TRAPCAD CODE
   - PLASMA ELECTRONS SIMULATIONS

Biri

Spaedtke

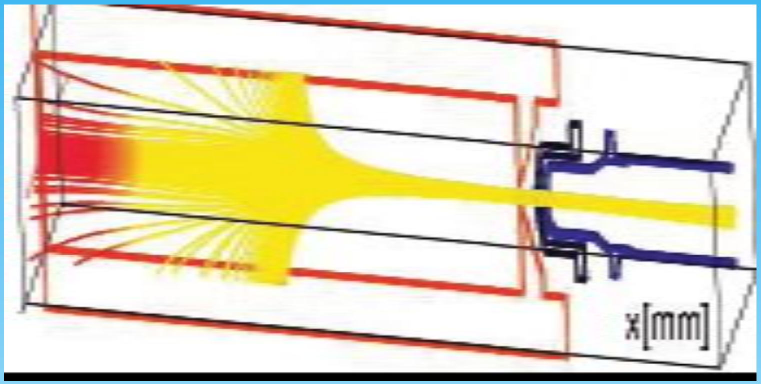
4. THE KOBRA3-INP CODE
   - TRANSFER FROM TRAPCAD TO KOBRA
5. ION EXTRACTION FROM INSIDE THE PLASMA CHAMBER

MOTIVATION

1. Ions extraction simulation from ECR Ion Sources: many attempts.

Partial results so far (pure reproducing of the the experimental results).

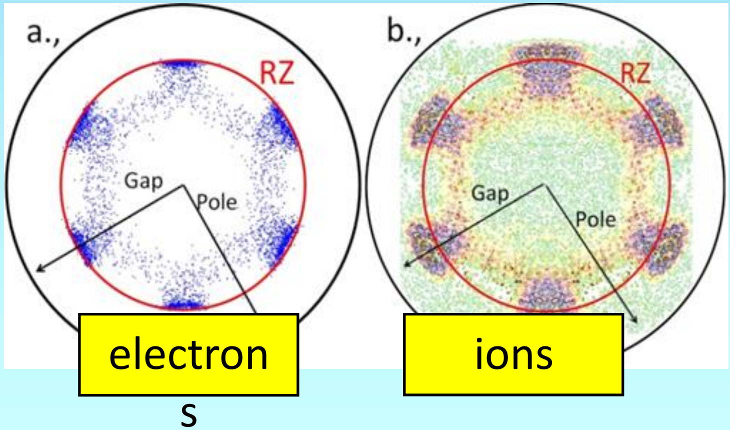
Latest GSI-model: ions start in the plasma on magnetic field lines passing through the extraction aperture.



P. Spädtke et al., 20th Int. Ws on ECRIS, Sydney, Austalia, 2012

2. Simulation of ECRIS plasma electrons: their positions may correspond to the positions of ions.

Basis: visible-light plasma photos and energy-filtered X-ray photos of argon plasmas.



R. Rácz et al., Plasma Sources Sci. and Tech. 20 (2011) 025002(7)

MOTIVATION

1. Ions extraction simulation from ECR Ion Sources: many attempts.

Partial results so far (pure reproducing of the the experimental resu

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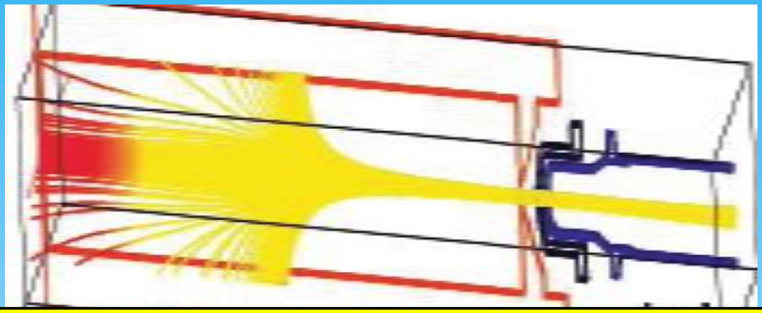
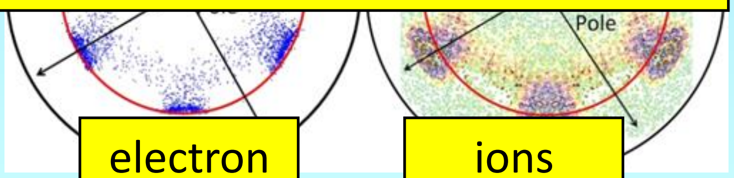


2. S
electrons

correspond to the positions of ions.

Basis: visible-light plasma photos and energy-filtered X-ray photos of argon plasmas.

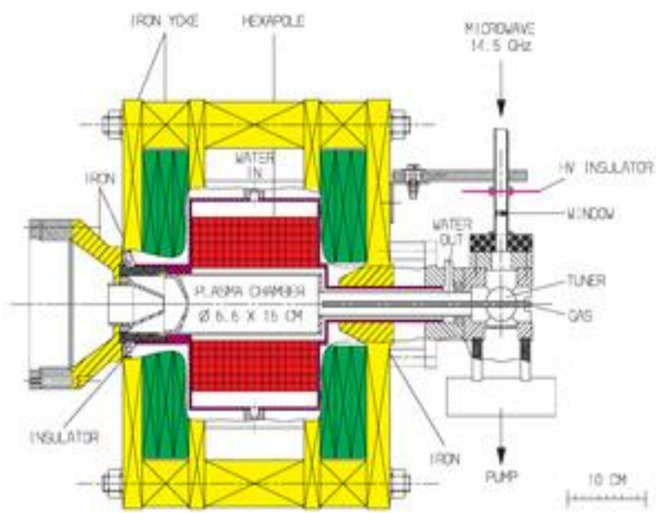
Therefore we decided to combine the two methods:
plasma **electron** cloud is simulated in a given ECRIS configuration
and
the coordinates of these electrons are used as the starting positions of **ions** to be extracted.

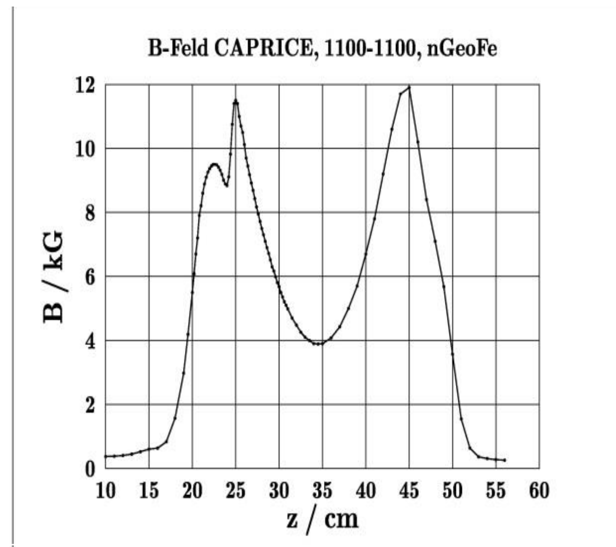


R. Rácz et al., Plasma Sources Sci. and Tech. 20 (2011) 025002(7)

The ECRIS to be simulated

GSI-CAPRICE, 14.5 GHz, 1.2 Tesla

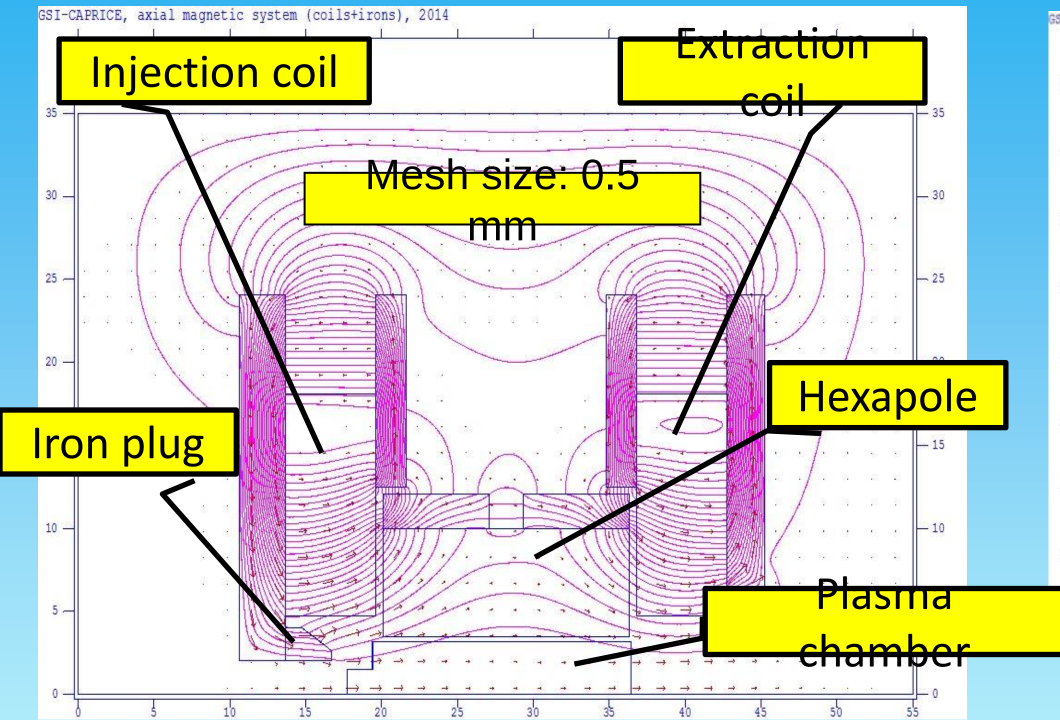


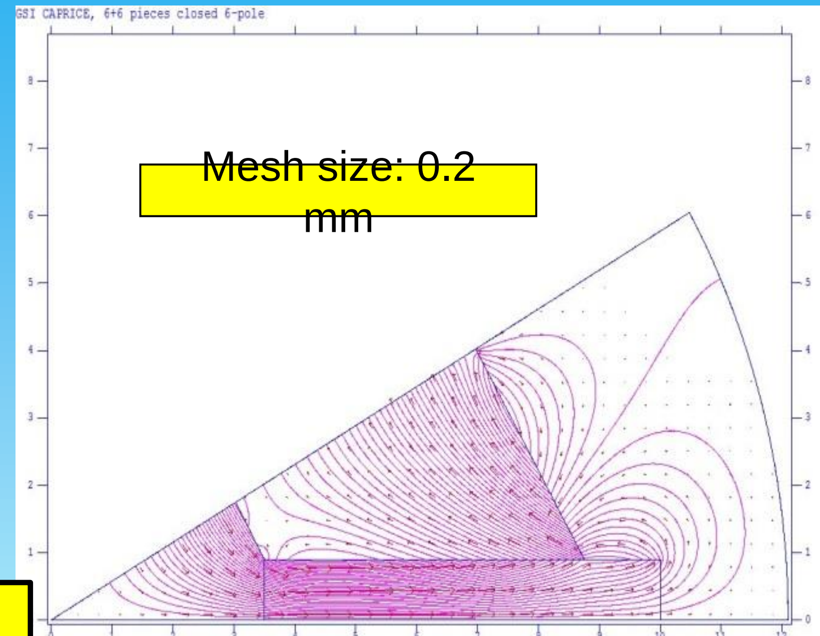


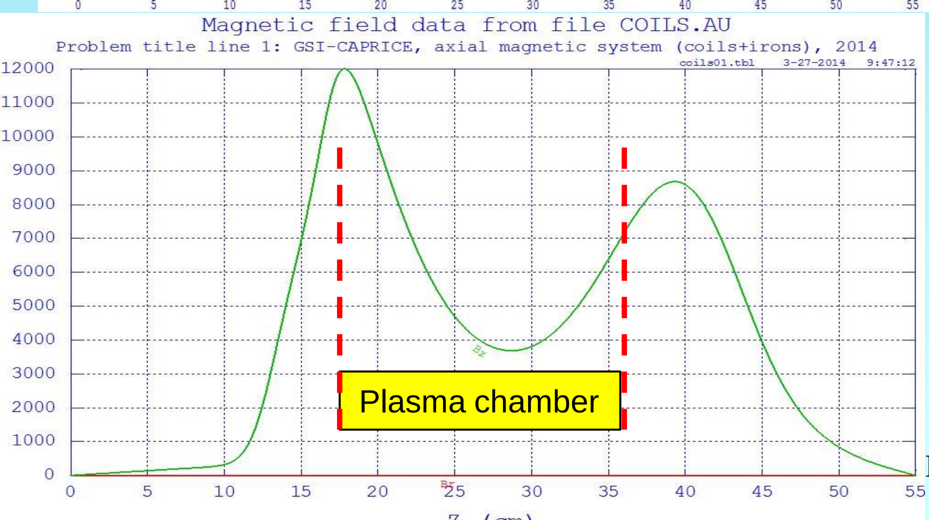
Plasma chamber length:	187 mm
Plasma chamber diameter:	63 mm
Injection coil current:	1100 A
Extraction coil current:	1100 A
Hexapole materials (VACODYM):	745HR/655HR

Russia

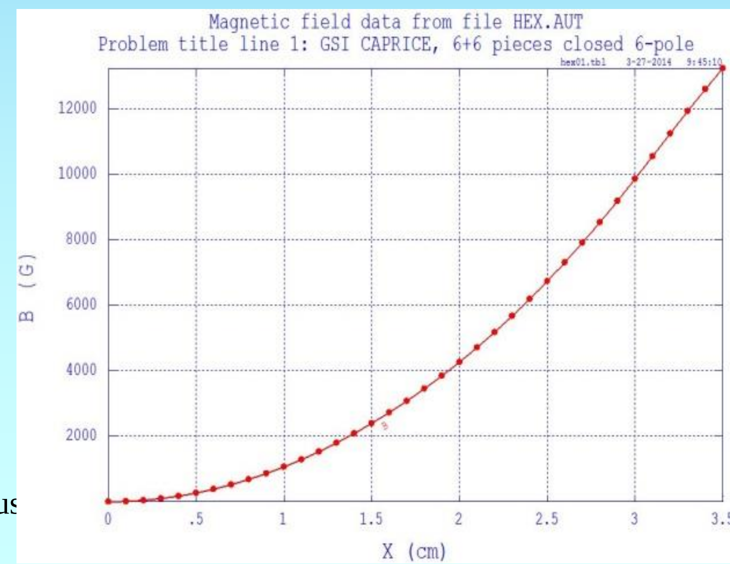
POISSON SUPERFISH calculation





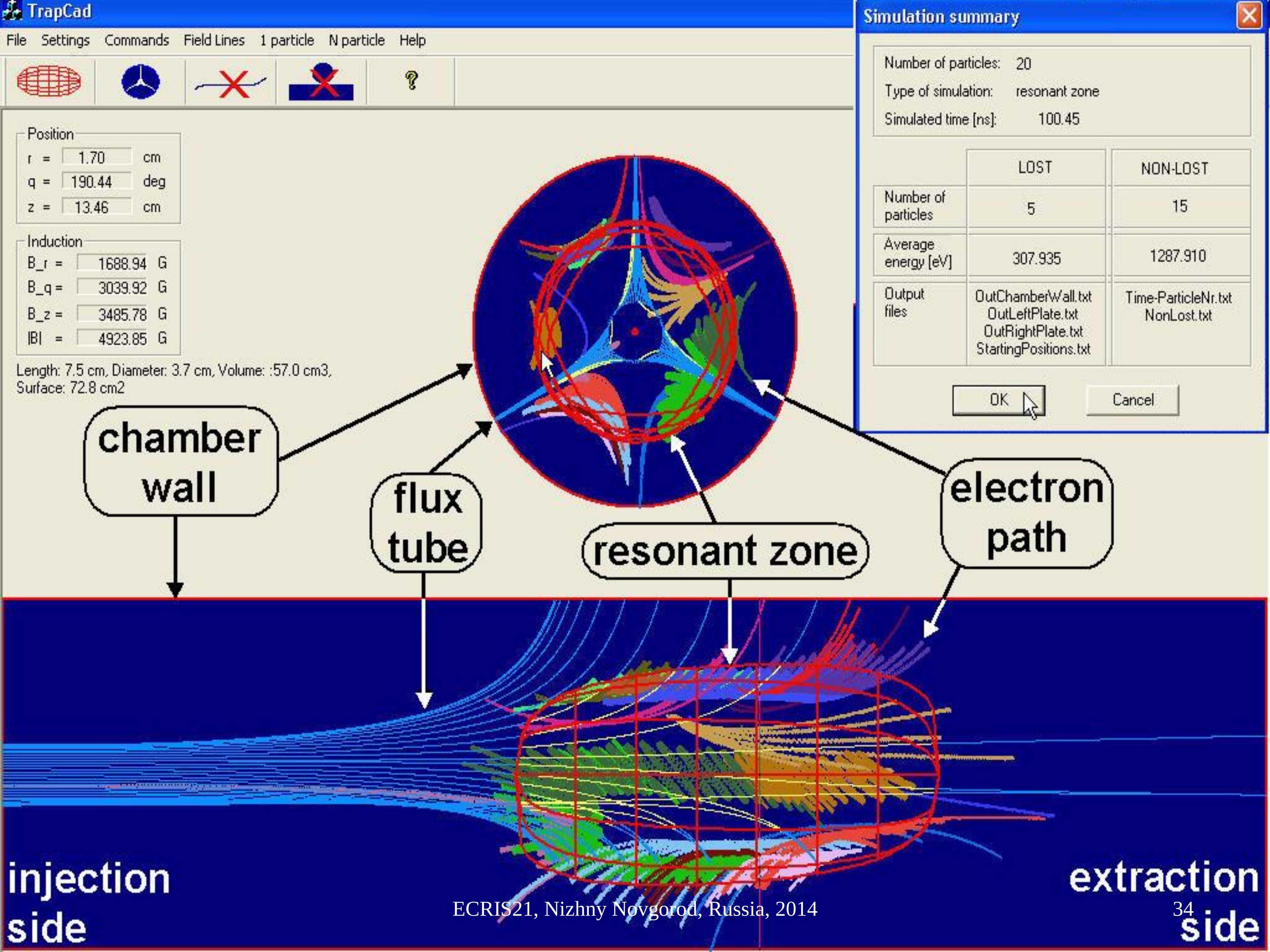


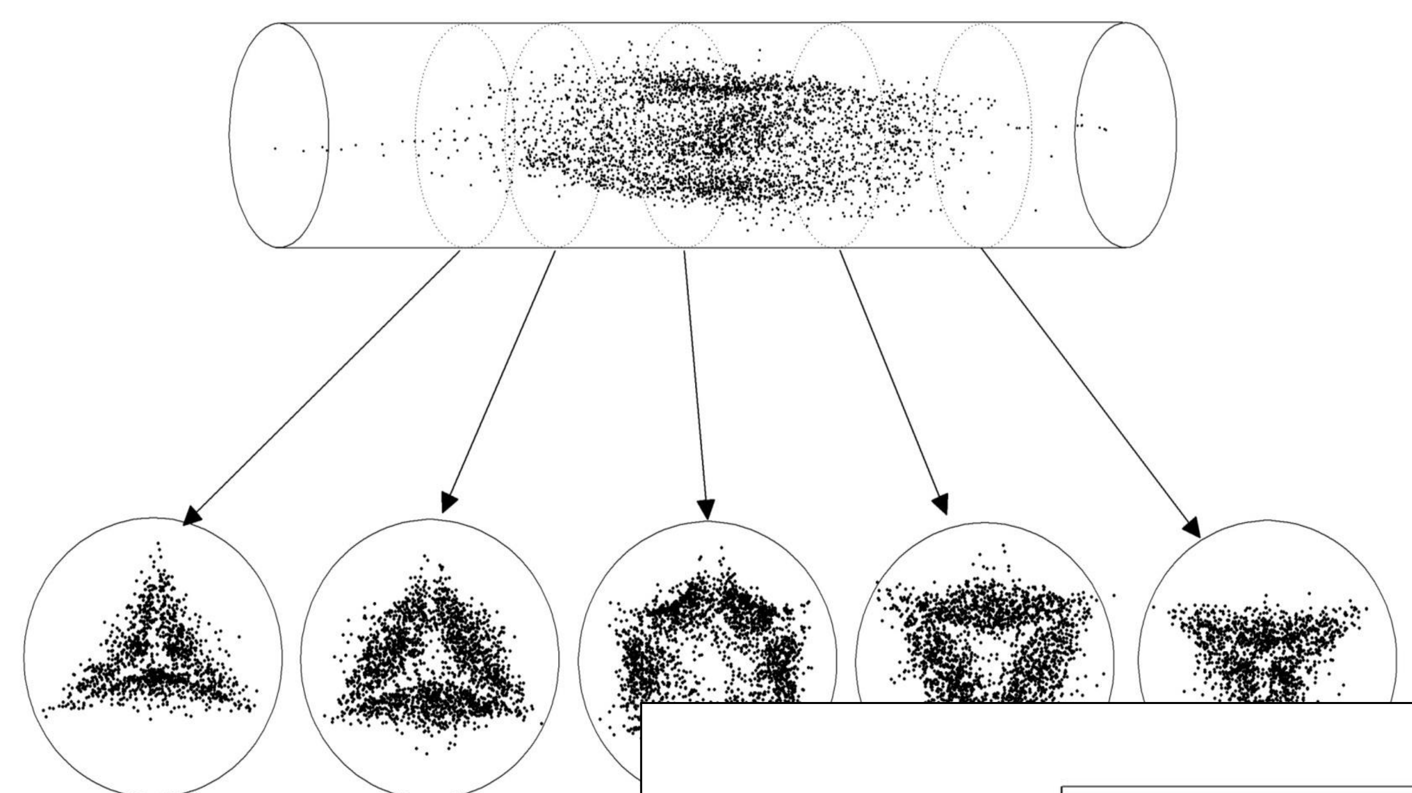
Novgorod, Rus

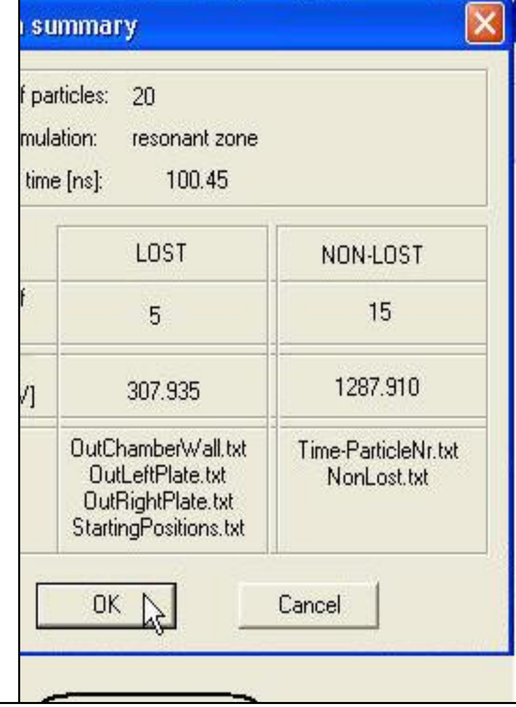


ECRIS plasma electrons simulation

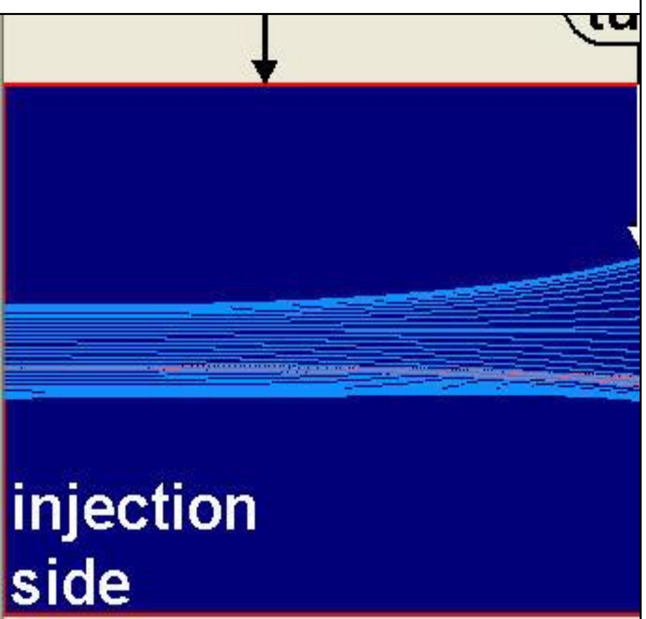
- TrapCAD code: since 1994…
- More than 20 users
- „Multiple-one-particle” code
- Realistic magnetic field (2D-3D)
- Stochastic ECR heating
- Magnetic field: PoissonSuperfish
- Only electrons
- Plasma potential not included
- Collisions not included


TrapCad
File Settings Commands Field Lines 1 particle N particle Help
Position
r = 1.70 cm
q = 190.44 deg
z = 13.46 cm
Induction
B_r = 1688.94 G
B_q = 3039.92 G
B_z = 3485.78 G
|B| = 4923.85 G
Length: 7.5 cm, Diameter: 3.7 cm, Volume: :57.0 cm3,
Surface: 72.8 cm2
Simulation summary
Number of particles: 20
Type of simulation: resonant zone
Simulated time [ns]: 100.45
LOST
NON-LOST
Number of particles
5
15
Average energy [eV]
307.935
1287.910
Output files
OutChamberWall.txt
OutLeftPlate.txt
OutRightPlate.txt
StartingPositions.txt
Time-ParticleNr.txt
NonLost.txt
OK
Cancel
chamber wall
flux tube
resonant zone
electron path
injection side
extraction side

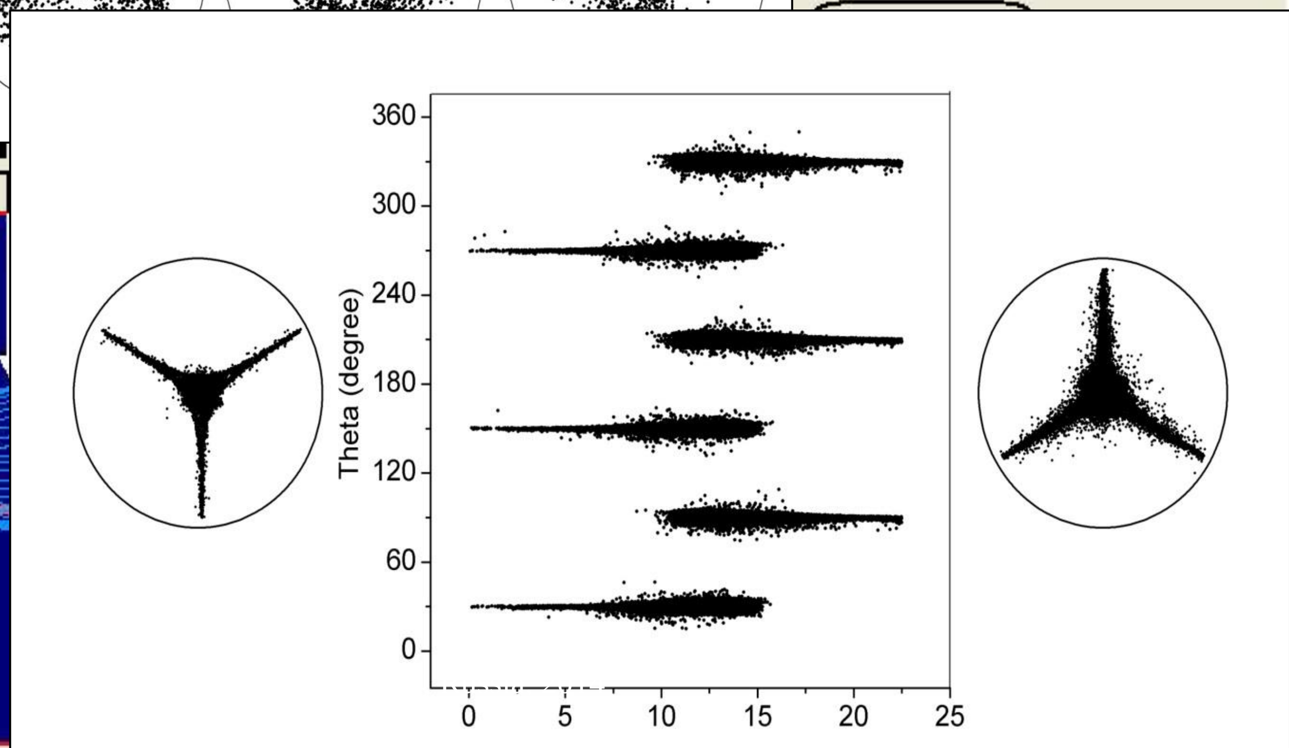




summary
f particles: 20
mulation: resonant zone
time [ns]: 100.45
LOST
NON-LOST
f
5
15
V]
307.935
1287.910
OutChamberWall.txt
OutLeftPlate.txt
OutRightPlate.txt
StartingPositions.txt
Time-ParticleNr.txt
NonLost.txt
OK
Cancel



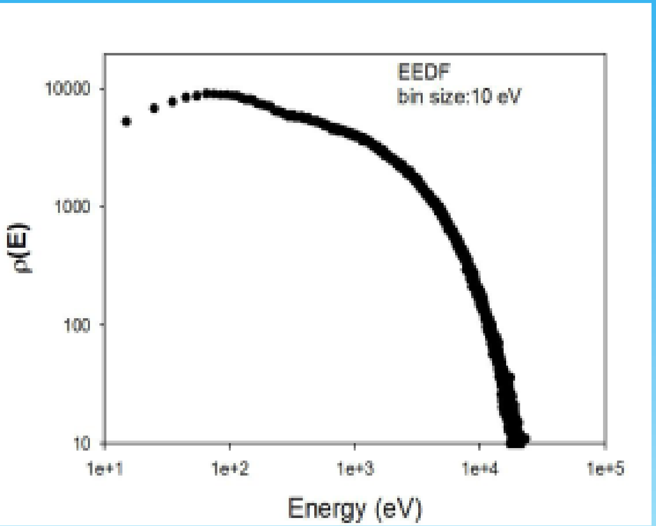
injection
side



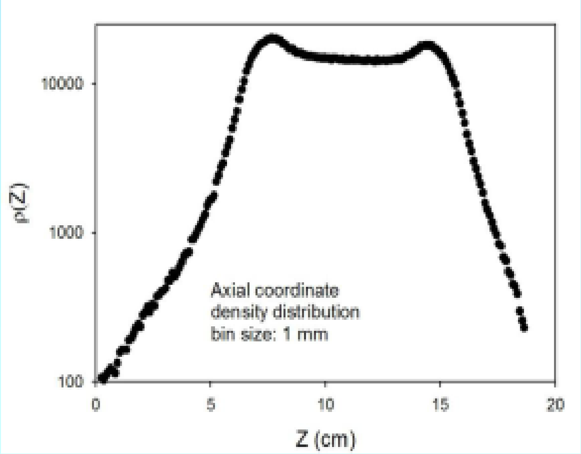
Theta (degree)
360
300
240
180
120
60
0
0
5
10
15
20
25

GSI-CAPRICE plasma electrons simulations

Number of electrons:	4 million
Start position (resonant surface)	5200 +/- 200 gauss
Perp. energy components:	1 - 100 eV, random
Parallel energy components:	1 - 100 eV, random
RF frequency:	14.5 GHz
RF power:	1000 W
Simulated time:	200 ns
Number of lost particles:	2396026 (59.9 %)
Number of non-lost particles:	1603974 (40.1 %)
Average energy of lost particles:	118 eV
Av. energy of non-lost particles:	2753 eV

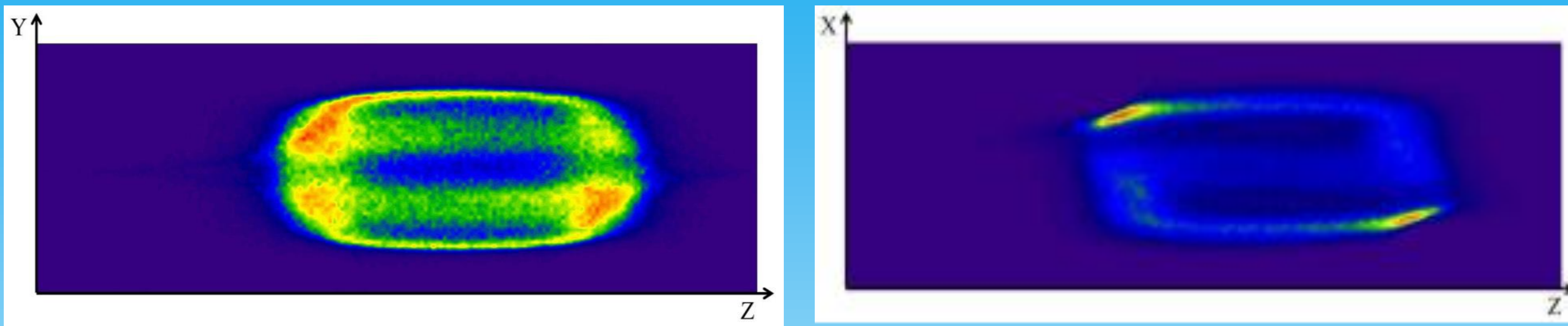


The electron energy distribution function (EEDF) of the non-lost electrons

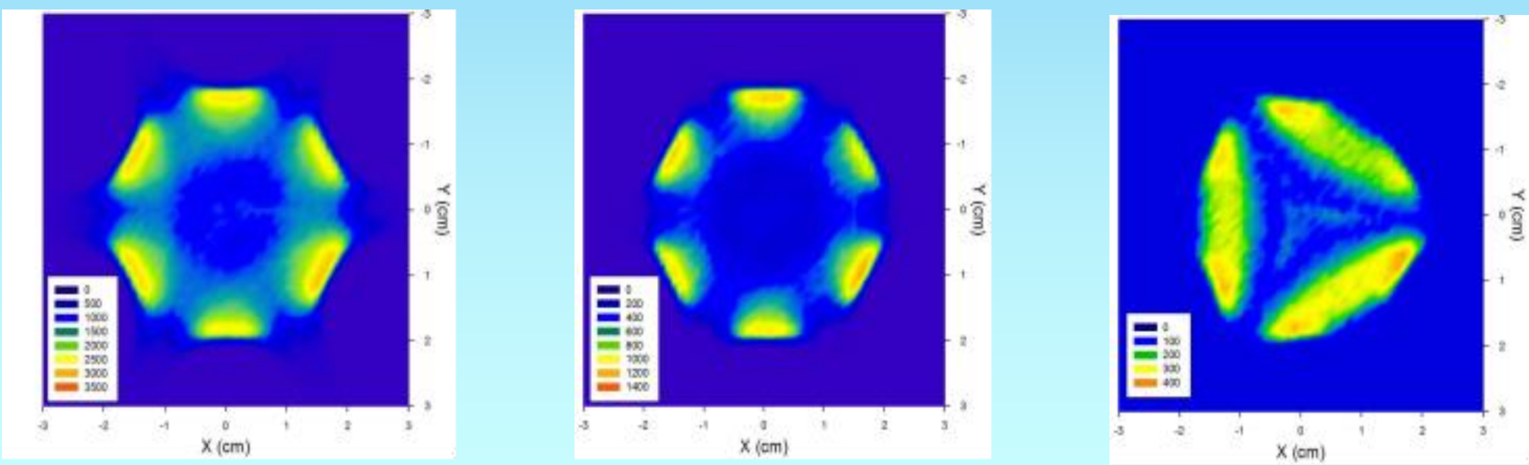


The axial distribution of the non-lost electrons. Left: injection side.

GSI-CAPRICE plasma electrons simulations

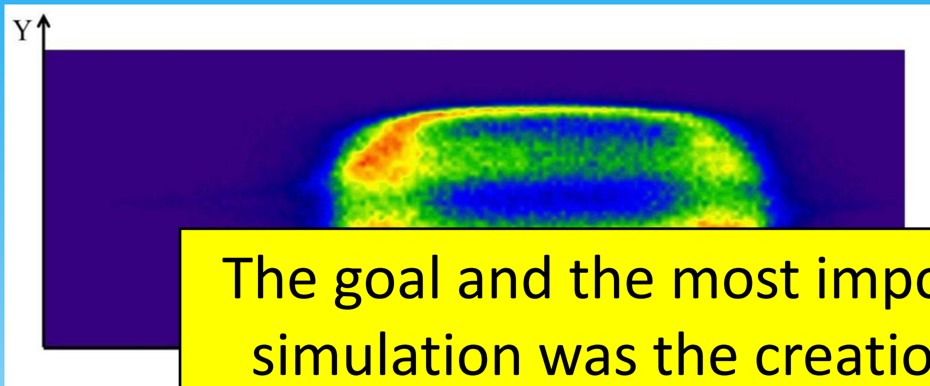


Radial (side-view) projection of the electron cloud from the direction of a magnetic gap (left) and from a magnetic pole (right).



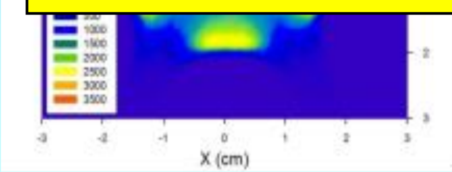
Axial (end-view) projection of the non-lost electrons. Left: all electrons, middle: warm electrons (3 keV <E< 10 keV), right: warm electrons close to the extraction side (Z>13cm).

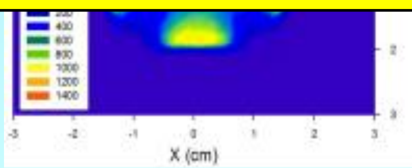
GSI-CAPRICE plasma electrons simulations

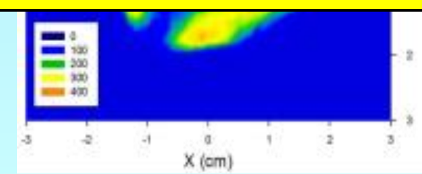


The goal and the most important result of the TrapCAD simulation was the creation of the huge **non_lost.txt** ASCII file containing the starting and ending coordinates (x, y, z) and the starting and ending energy (parallel, perpendicular, total) of all **non-lost electrons**.

This file was used as basic database for the simulation of the **ions extraction.**







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OUTLINE

1. MOTIVATION
2. THE ECRIS
3. THE TRAPCAD CODE
    - PLASMA ELECTRONS SIMULATIONS

Biri

Spaedtke

4. THE KOBRA3-INP CODE
    - TRANSFER FROM TRAPCAD TO KOBRA
5. ION EXTRACTION FROM INSIDE THE PLASMA CHAMBER

Perspectives

Atomki in ARES + MIDAS, 2014-15-16…

Task 1.

Experimental X-ray diagnostics with detectors/cameras to be continued
Two-frequency modes, frequency modulation: occasionally
Time-resolved plasma measurements: at enough manpower

Task 2:

Ions extraction simulation from inside the plasma chamber to be continued
The next steps (majority of the work) are at the GSI group side

Task 3:

Metal plasmas: only small more efforts are planned.
High intensity, low-charged, slow ions are required (implanter mode)
Goal: to decrease the irradiation time, to save manpower